



New hadronic currents in TAUOLA: for confrontation with the experimental data

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Abstract

The status of implementation of new hadronic currents into the Monte Carlo system for simulation of τ -lepton production and decay in high-energy accelerator experiments is reviewed. Since the τ -lepton conference in 2010 substantial progress was achieved: (i) For the TAUOLA Monte Carlo generator of τ -lepton decays, automated and simultaneous use of many versions of form factors for the calculation of optional weights for fits was developed and checked to work in the Belle and BaBar software environment. Alternative parameterizations of hadronic currents based on the Resonance Chiral approach are available now. This was achieved for more than 88% of the total τ hadronic width. (ii) the TAUOLA universal interface based on HepMC (the C++ event record) is available. This is the case for C++ users of PHOTOS Monte Carlo for radiative corrections in decays, as well. An algorithm for weighted events to explore spin effects in analysis of hard processes was prepared. (iii) Kernels featuring a complete first-order matrix element are available now for PHOTOS users interested in decays of Z and W bosons. New tests with different options of matrix elements for those and for K_3 decays are available as well.

Presented results illustrate the status of the projects performed in collaboration with Zofia Czyczula, Nadia Davidson, Tomasz Przedziński, Olga Shekhovtsova, Elżbieta Richter-Wąs, Pablo Roig, Qingjun Xu and others.

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1. Introduction

The TAUOLA package [1, 2, 3, 4] for simulation of τ -lepton decays and PHOTOS [5, 6, 7] for simulation of QED radiative corrections in decays, are computing projects with a rather long history. Written and maintained by well-defined (main) authors, they nonetheless migrated into a wide range of applications where they became ingredients of complicated simulation chains. As a consequence, a large number of different versions are presently in use. Those modifications, especially in case of TAUOLA, are valuable from the physics point of view, even though they often did not find the place in the distributed versions of the program. From the algorithmic

point of view, versions may differ only in details, but they incorporate many specific results from distinct τ -lepton measurements or phenomenological projects. Such versions were mainly maintained (and will remain so) by the experiments taking precision data on τ leptons. Interesting from the physics point of view changes are still developed in FORTRAN. That is why, for convenience of such partners, part of the TAUOLA should remain in FORTRAN for a few forthcoming years.

Many new applications were developed in C++, often requiring a program interface to other packages (e.g., generating events for LHC, LC, Belle or BaBar physics processes). Fortunately, co-existence of FORTRAN with

C++ is not a problem, at least not from the software point of view.

The program structure, was presented during τ conferences, and we will not repeat it here. This time, let us concentrate on new hadronic currents based on the Resonance Chiral approach. We will also report on prepared techniques useful for fits. Analyses of high precision, high-statistics data from Belle and BaBar are expected to progress from these solutions. Other aspects of the project such as interfaces for applications based on HepMC [8] event record or new tests and weighting algorithms for spin effects in production processes will be mentioned as well.

Our presentation is organized as follows: Section 2 is devoted to the discussion of optional weights in TAUOLA and their use for fits to experimental data. Status of implementation of new currents for hadronic decays which can be confronted with (tuned to) data using such weights enabling simultaneous control of all experimental effects will be mentioned, but results of this work are covered in another talk of the conference. In section 3 we concentrate on PHOTOS Monte Carlo for radiative corrections in decays. Section 4 is devoted to new interfaces of TAUOLA and PHOTOS based on HepMC and written in C++. Work on interface to genuine weak corrections, transverse spin effects and new tests and implementation bremsstrahlung kernels will be presented as well. Short section 5, is devoted to MC-TESTER; the program designed for semi-automatic comparisons of simulation samples originating from different programs and heavily used in our projects.

Because of the limited space of the contribution, and sizeable amount of results, some of them will not be given in the proceedings. They find their place in publications, prepared with coauthors listed in the Abstract. For these works, the present paper may serve as a summary.

2. Approach of Resonance Chiral lagrangians and TAUOLA Monte Carlo

In another talk [9] of the conference, an approach, based on Resonance Chiral Lagrangian, for calculations of hadronic currents to be used in TAUOLA was described. That is why, we do not need to repeat it here. In [10] implementation of those currents is documented in a great detail. Technical tests are available with this reference as well. Let us limit ourselves to one example, Fig. 1.

Physics of τ lepton decays requires sophisticated strategies for the confrontation of phenomenological

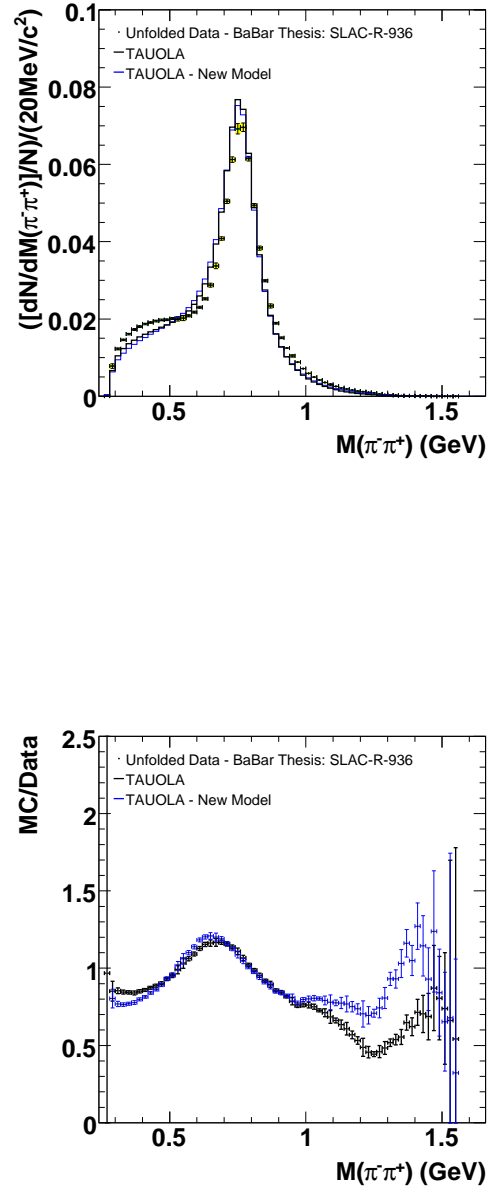


Figure 1: Invariant mass distribution of the $\pi^+\pi^-$ pair in $\tau \rightarrow \pi^+\pi^-\pi^-\nu_\tau$ decay. Lighter grey histogram is from our new model, darker grey is from default parametrization of TAUOLA c1e0. The unfolded BaBar data are taken from Ref. [11]. The plot on top presents distribution in invariant mass of $\pi^+\pi^-$ pair, and the one on bottom ratios between Monte Carlo results and data (courtesy of Ian Nugent).

models with experimental data. On one hand, high-statistics experimental samples are collected, and the obtained precision is high, on the other hand, there is a significant cross-contamination between distinct τ decay channels. Starting from a certain precision level all channels need to be analyzed simultaneously. Change of parameterization for one channel contributing to the background to another one may be important for the fit of its currents. This situation leads to a complex configuration where a multitude of parameters (and models) needs to be simultaneously confronted with a multitude of observables. One has to keep in mind that the models used to obtain distributions in the fits may require refinements or even substantial rebuilds as a consequence of comparison with the data. The topic was covered in detail in the τ Section of Ref. [19].

From the statistical point of view it is best to resolve such a system in one automated step using, for example, a method such as described in [20, 21]. This can be of course very dangerous from the point of view of systematic error control. But we will not elaborate on this point any further. From the technical side it is necessary to calculate for each generated event (separately for each present in it decay of τ^+ and/or τ^-) alternative weights; the ratios of the matrix element squared obtained with new currents, and the one actually used in generation. Then, the vector of weights can be obtained and used in fits. We have checked that such a solution not only can be easily installed into TAUOLA as a stand-alone generator, but it can also be incorporated into the simulation frameworks of Belle and BaBar collaborations. The weights can be calculated after the simulation of detector response is completed. Only then choice of parameters for the hadronic currents has to be performed and the fits completed.

We take into account convenience for necessary software upgrades in experiments. Instead of a completely new system, only a dedicated patch is prepared.

3. PHOTOS Monte Carlo for bremsstrahlung and its systematic uncertainties

Thanks to exponentiation properties and factorization, the bulk of the final state QED bremsstrahlung can be described in a universal way. However, the kinematic configurations caused by QED bremsstrahlung are affecting in an important way signal/background separation. It may affect selection criteria and background contaminations in quite complex and unexpected ways. In many applications, not only in τ decays, such bremsstrahlung corrections are generated with the help of the PHOTOS Monte Carlo. That is why it is of

importance to review the precision of this program as documented in Refs. [5, 6, 7]. For the C++ applications, the version of the program is available now. It is documented in Ref. [15].

In C++ applications, the complete first-order matrix elements for the two-body decays of the Z [16] and W [26] decays into a lepton pair are now available. Kernels with complete matrix elements, for the decays of scalar B mesons into a pair of scalars [25] are available for the C++ users as well. For $K \rightarrow l\nu\pi$ and for $\gamma^* \rightarrow \pi^+\pi^-$ decays [26, 27] matrix element based kernels are still available for tests only. Properly oriented reference frames are needed in those cases. It will be rather easy to integrate those NLO kernels into the main version of the program, because of better control of the decay particle rest frame than in the FORTRAN interface.

In all of these cases the universal kernel of PHOTOS is replaced with the one matching an exact first-order matrix element. In this way terms necessary for the NLO/NLL precision level are implemented¹. A discussion relevant for control of program systematic uncertainty in $\tau \rightarrow \pi\nu$ decay can be found in Ref. [29].

The algorithm covers the full multiphoton phase-space and becomes exact in the soft limit. This is rather unusual for NLL compatible algorithms. One should not forget that PHOTOS generates weight-one events, and does not exploit any phase space ordering. There is a full phase space overlap between the one where a hard matrix element is used and the one for iterated photon emission. All interference effects (between consecutive emissions and emissions from distinct charged lines) are implemented with the help of internal weights.

The results of all tests of PHOTOS with a NLO kernel confirm sub-permille precision level. This is very encouraging, and points to the possible extension of the approach outside of QED (scalar QED). In particular, to the domain of QCD or to QED when phenomenological form factors for interactions of photons need to be used. For that work to be completed, spin amplitudes need to be studied. Let us point to Ref. [30] as an example.

New tests of PHOTOS are available from the web page [31]. In those tests, results from the second-order matrix element calculations embedded in KKMC [32] Monte Carlo are used in case of Z decay. For W decays com-

¹Note that here the LL (NLL) denotes collinear logarithms (or in case of differential predictions terms integrating into such logarithms). The logarithms of soft singularities are taken into account to all orders. This is resulting from mechanisms of exclusive exponentiation [28] of QED. The algorithm used in PHOTOS Monte Carlo is compatible with exclusive exponentiation. Note that our LL/NLL precision level would even read as respectively NLL/NNLL level in some naming conventions of QCD.

parisons with electroweak calculations of Refs. [17, 18] are shown.

4. TAUOLA universal interface and PHOTOS interface in C++

In the development of packages such as TAUOLA or PHOTOS, questions of tests and appropriate relations to users' applications are essential for their usefulness. In fact, user applications may be much larger in size and human efforts than the programs discussed here. Good example of such 'user applications' are complete environments to simulate physics process and control detector response at the same time. Distributions of final state particles are not always of direct interest. Often properties of intermediate states, such as a spin state of τ -lepton, coupling constants or masses of intermediate heavy particles are of prime interest. As a consequence, it is useful that such intermediate state properties are under direct control of the experimental user and can be manipulated to understand detector responses. Our programs worked well with FORTRAN applications where HEPEVT event record is used. For the C++ HepMC [8] case, interfaces were rewritten, both for TAUOLA [14] and for PHOTOS [15]. The interfaces and as a consequence the programs themselves were enriched; for PHOTOS new Matrix element kernels are available; for TAUOLA interface, a complete (not longitudinal only) spin correlations are available for Z/γ^* decay. Electroweak corrections taken from Refs. [17, 18] are also used. For the scheme of programs communications see Fig. 2. In this spirit an algorithm [33] to study detector response to spin effects in Z, W and H decays, was developed. Such modular organization opens ways for further efficient algorithms to understand detector systematics, but at the same time responsibility to control software precision must be shared by the user. For that purpose automated tests of MC-TESTER were prepared [12]. New functionalities were introduced into the testing package [13]. In particular, it works now with the HepMC event record, the standard of C++ programs and the spectrum of available tests is enriched.

5. MC-TESTER its user defined tests and Grid libraries.

Our work on MC-TESTER reached maturity with Ref. [13]. As in the past, the program main purpose remains benchmarking the decay part of different Monte Carlo chains. Generated events have to be stored in event records: be it of FORTRAN or C++. Default distributions consist of all possible invariant masses which

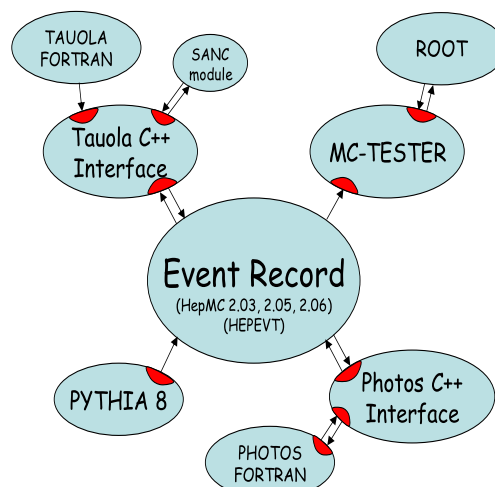


Figure 2: Scheme of Monte Carlo simulation system with communication based on event record.

are automatically generated and stored for each found decay channel of the particle under test. Then, at the analysis step, information from a pair of such runs may be compared and represented in the form of tables and plots. At present, users macros can be easily installed, in particular all demo distributions given in papers on C++ interfaces for TAUOLA [14] and PHOTOS [15] were obtained in that way.

Set-up's for benchmarking the interfaces, such as interface between τ -lepton production and decay, including QED bremsstrahlung effects are also prepared in that way. The updated version of MC-TESTER was found useful for FORTRAN [7, 16] and for C++ [15] examples where spurious information (on soft photons) was removed.

Finally, let us mention that the program is available through the Grid Project LCG/Genser web page, see Ref. [34] for details. This is the case for TAUOLA C++ and for PHOTOS C++ as well. The FORTRAN predecessors have already been available in this and for a longer time now.

6. Summary and future possibilities

Versions of the hadronic currents available for the TAUOLA library until now, are all based on old models and experimental data of 90's. Implementation of new currents, based on the Resonance Chiral Lagrangian approach is now prepared and tested from the technical side. Methods for efficient confrontation with the experimental data are prepared as well. Once comparison with Belle and BaBar data successfully completed, new parameterizations will be straightforward for use in a

broad spectrum of applications in FORTRAN and C++ environments.

The status of associated projects: TAUOLA universal interface and MC-TESTER was reviewed. Also the high-precision version of PHOTOS for radiative corrections in decays, was presented. All these programs are available now for C++ applications thanks to the HepMC interfaces.

New results for PHOTOS were mentioned. For the leptonic Z and W decays the complete next-to-leading collinear logarithms effects can now be simulated in C++ applications. However, in most cases these effects are not important, leaving the standard version sufficient. Thanks to this work the path for fits to the data of electromagnetic form factors is opened, e.g. in the case of K_{l3} decays.

The presentation of the TAUOLA general-purpose interface in C++ was given. It is more refined than the FORTRAN predecessor. Electroweak corrections can be used in calculation of complete spin correlations in Z/γ^* mediated processes. An algorithm for study of detector responses to spin effects in Z , W and H decays was shown.

The present version of MC-TESTER is stable now. It works with HepMC of C++ and enables user defined tests in experiments' software environments. We used the tool regularly all over our projects.

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